RESEARCH

Effect of microwave pre-treatment on air-drying orange (Beauregard) kumara slices

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Abstract

The effects of slice thickness, microwave pre-treatment, and drying temperature on drying orange kumara slices were investigated. The highest drying rate, with minimal loss of colour, occurred at 80°C. Slice thickness did not significantly influence colour but drying time increased with slice thickness. The drying curves fitted the Page thin-layer drying model. Two minutes microwave pre-treatment significantly reduced overall drying time and improved colour but increased shrinkage.
Keywords: Orange sweet potato, kumara, drying, microwave pre-treatment

Introduction

Sweet potato (*Ipomoea batatas*) is an important food crop with a world-wide production in 2012 of 103.1 million tonnes [1]. In developing nations in particular, it is the fifth most important food crop [2]. It is rich in dietary fibre and minerals and commonly eaten boiled or roasted. It can be can be dried and milled into flour, used as a thickener in soup or gravy, or incorporated into snack-foods and bakery products [3]. In Asia, sweet potato is also widely used in ready-to-eat foods [4]. Sweet potato starch also has a wide range of uses [5].

Sweet potato not destined to be eaten fresh may be dried after harvest to extend its shelf life and reduce mass for transportation. Air drying may be enhanced by combining it with other technologies, particularly microwave treatment [6-13], although commercial microwave treatment is currently only applied on a relatively small scale [12].

The quality of a dried product depends on the drying process and processing conditions [14]. Dehydration, especially at high temperatures and for longer drying times, can adversely affect product texture, flavour, colour, nutrient content and rehydration [15]. Microwave treatment often creates non-uniform heating, which can lead to localised overheating and burning [16]. Microwave treatment does not appear to have been used for drying orange sweet potato and no drying trials on New Zealand sweet potato (kumara) have been reported in the literature. Because optimal drying conditions for biological materials are difficult to predict they are typically determined by experimentation. The aim of this work was firstly to determine the highest drying temperature (which typically reduces drying time) that did not significantly affect the colour of orange kumara (based on a qualitative assessment), and secondly to determine the whether microwave pre-treatment reduced the overall drying time without significant colour changes.

Methods and materials

Wray and Ramaswamy [11] summarised three different strategies when applying microwaves to assist with convection drying for foods:

1. Apply microwaves at the start of the process. This has the effect of achieving high initial drying rates and opening up the structure of the material to facilitate moisture transfer from the centre of the object to its surface.
2. Apply microwaves once the drying rate has started to fall (i.e. at the end of the constant rate period), so drying rate is enhanced. This is also known as 'booster drying' [6]. Since microwaves penetrate below the surface of the object, it helps increase the rate of moisture migration from the centre to the surface. This compares with air drying, which relies on moisture moving from high moisture regions to regions with lower moisture content.
3. Apply microwaves at the end of the process, also known as 'finish drying' [6]. This can assist in removing bound water and can reduce the amount of shrinkage. Finish drying is sometimes used on an industrial scale, for potatoes in particular [12].

All three strategies have potential to be beneficial. However, long-term exposure to microwaves can adversely affect quality so it is highly unlikely microwave treatment can be applied throughout the drying process. In this study, microwave treatment prior to the start of the air drying process was used because it was the simplest to implement.

Materials and apparatus

Orange (Beauregard) kumara used for the drying experiments were obtained from a local market in Hamilton, New Zealand. The samples were obtained fresh on the day of experimentation. The pointed ends of each kumara were trimmed with a knife and then the unpeeled kumara was sliced into 10-, 15- and 20-mm slices.

The drying experiments were performed in a Contherm Digital series convection oven with a 0.85m × 0.6m drying tray. The heat transfer coefficient within the oven was estimated to vary between 15 and 30 W m^{-2} K^{-1}, and the relative humidity of the air was approximately 10%. Air temperature was controlled with a proportional controller. Mass loss of samples was recorded using a digital balance with a sensitivity of 0.1g. Microwave pre-treatment was achieved in a Sharp™ microwave with full power of 800W and 2450MHz operating frequency. All colour changes were assessed qualitatively.

Procedure

The experiments were performed at three oven temperatures: 70°C, 80°C and 90°C. Three slices of the same thickness for each trial were placed on the tray within the dryer and total sample mass was recorded every 15 or 20 minutes using a Mettler balance. At least two replicates were performed for each trial. A digital photograph of the samples was taken every hour and used for qualitative visual assessment.

The optimum microwave pre-treatment time was determined by trial and error. Slices at room temperature were microwaved on the 'full' setting for 2, 3 and 4 minutes.

Trials were performed both with and without the microwave pre-treatment at three different oven temperatures and slice thicknesses.

The dry-basis moisture content (X) was used in the analyses:

$$X = \frac{m_w}{m_s}$$

where m_w is the mass of water and m_s is the mass of solids. Normalised moisture content (NMC) which indicates the relative change in moisture content is defined by:

where X_0 is the initial moisture content

$$NMC = \frac{X}{X_0}$$

Results and discussion

Convection-only trials

A typical drying profile for 10mm kumara slices dried at 70°C (Figure 1) showed an approximately linear falling rate, similar to reports for other root vegetables [13]. Drying time, as expected, decreased with increased oven temperature (Figure 2) and for thinner slices. For example, the time required to reach a NMC of 0.2 decreased from 690 min at 70°C to 500 min at 80°C and 300 min at 90°C. The effect of slice thickness was much less significant than oven temperature for the range of temperatures and slice thicknesses used in this study.

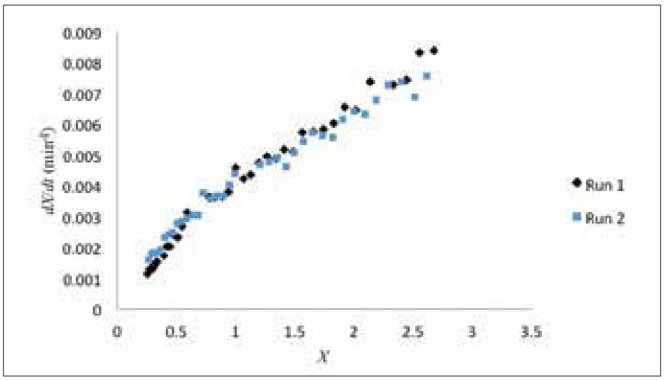

Figure 1: Drying rate with moisture content for 10-mm orange kumara slices dried at 70°C.

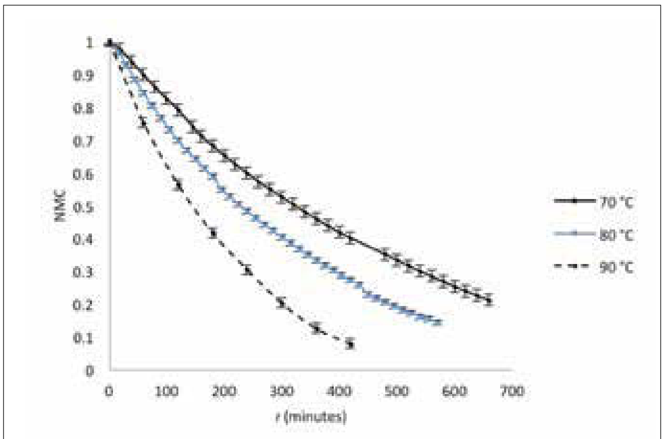

Figure 2: Effect of drying temperature on drying time of 15-mm orange kumara slices.

Several models have been proposed for modelling drying curves [17]. Based on the R^2 value, the Page thin-layer drying model (Eq. 3, assuming equilibrium moisture content is negligible) was the simplest model for a satisfactory fit:

$$NMC = \frac{X}{X_0} = \frac{m_w}{m_{wo}} = \exp(-kt^n)$$

Table 1 shows the empirical fitting parameters (k and n) for the Page model applied to the drying curves (time in minutes), and the R^2 values used to indicate goodness of fit of the model.

Slice thickness		Temperature		
		70 °C	80 °C	90 °C
10 mm	k	0.0012	0.00388	0.00798
	n	1.15	0.949	0.929
	R2	0.9998	0.9964	0.9948
15 mm	k	0.000564	0.00224	0.00975
	n	1.22	1.05	1.19
	R2	0.9863	0.9995	0.9987
20 mm	k	0.000747	0.00297	0.00278
	n	1.09	0.876	0.982
	R2	0.9999	0.9993	0.9998

Table 1: Model parameters (k, n) and R^2 values for Page model (Eq. 3) fitted to drying curves (minutes as unit of time)

Figure 3 shows how the appearance of the kumara was affected by drying temperature and slice thickness). Kumara dried at 70°C (top row) were still orange after 10 hours drying while the slices dried at

Figure 3: Orange kumara slices dried at 70°C (top row), 80°C (middle row), or 90°C (bottom row) for 0h (left column), 4h (middle column) or 10h (right column).

Figure 4: Effect of microwave treatment on orange kumara: (a) fresh kumara; (b) 2 minutes microwave pre-treatment; (c) 3 minutes microwave pre-treatment; (d) 4 minutes microwave pre-treatment.

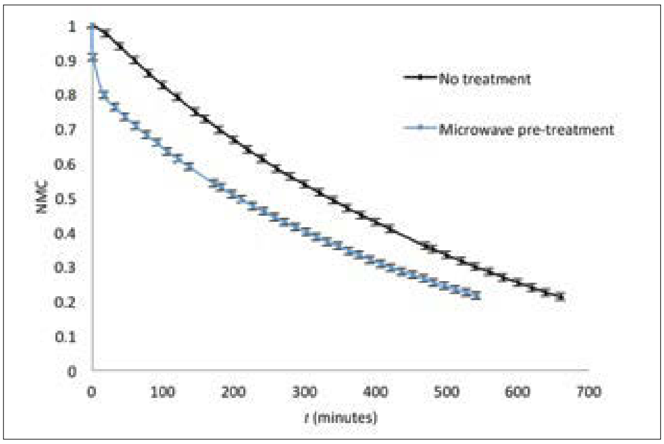

Figure 5: Effects of 2 min microwave pre-treatment on drying 15-mm orange kumara slices at 70°C (n=2).

80°C (middle row) had become yellow after 10 hours. When dried at 90° (bottom row), slices were no longer orange after 4 hours and had turned grey after 10 hours. The orange colour, which decreased substantially with drying time and temperature, is attributed to β-carotene levels. Based on the visual assessment of the colour of the kumara, it is recommended that orange kumara are dried at temperatures below 80°C.

Microwave-assisted trials

The maximum exposure to microwaves without significant discolouration and cracking/shrinkage of the samples of orange kumara slices was two minutes (Figure 4). A 2-minute microwave pre-treatment significantly reduced drying time. For example, drying pre-treated 15-mm kumara slices at 70°C took 2 hours less to reach a normalised moisture content of 0.25 than untreated slices (Figure 5).

Kumara that had been microwave pre-treated initially had higher drying rates than untreated kumara (Figure 6) and the NMC decreased from 1 to less than 0.8 in 15 minutes. The drying rate decreased as moisture content of the slices decreased and approached the same rate

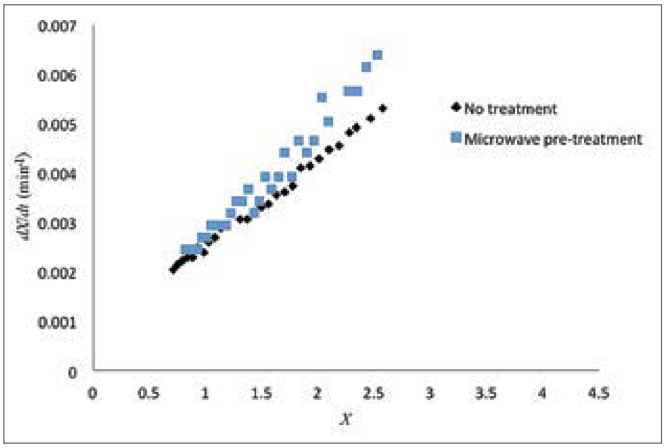

Figure 6: Effects of 2 min microwave pre-treatment on drying rates for 15-mm kumara slices dried at 70°C.

as untreated kumara slices. The rapid drying rate during microwave pre-treatment may partly be due to microwaving creating a high internal temperature in the kumara slices, which induces a temperature profile (and therefore increased driving force for moisture movement) from the interior to the surface. The temperature profile becomes less significant as drying progresses so drying rate decreases. Untreated slices are heated from room temperature and drying depends on the driving force between the interior and air temperature at the boundary of the slice.

Microwave pre-treatment and drying temperature affected appearance of the kumara slices after 4 or 10 hours drying (Figures 7 and 8). Kumara subjected to microwave pre-treatment were more orange than untreated kumara, particularly after 4 hours drying. A similar effect has been reported for purple-fleshed kumara [18] where microwave treatment improved colour retention. However, microwave pre-treated kumara slices were more deformed and shrunken than untreated samples.

Figure 7: Appearance of kumara slices after 4 h drying at 70°C (top row), 80°C (middle row) or 90°C (bottom row). Left column has no pre-treatment; right column has 2 min microwave pre-treatment.

Figure 8: Appearance of kumara slices after 10 h drying at 70°C (top row), 80°C (middle row) or 90°C (bottom row). Left column has no pre-treatment; right column has 2 min microwave pre-treatment.

Conclusions

To maximise colour retention, drying temperature for drying orange kumara should not exceed 80°C. Both shrinkage and colour loss are lower when kumara is dried at 70 °C, and significantly less than when slices are dried at 90 °C. Slice thickness did not have a significant influence on colour changes. A two-minute microwave pre-treatment significantly reduced drying time and appeared to improve colour retention compared to air drying. However, microwave pre-slices were more deformed. Microwaving for longer than two minutes significantly increased discoloration and deformation.

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Nomenclature

k	fitting parameter for Pages model
m	mass (kg)
n	fitting parameter for Pages model
NMC	Normalised moisture content (X/X_0)
t	time (min)
X	dry-basis moisture content

Subscripts

$_0$	initial value
$_s$	solids
$_w$	water